No. 16

ON CREATIVE DESIGN STUDY IN AN ENGINEERING UNDERGRADUATE COURSE

by

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TECHNICAL REPORT

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1. SUMMARY

This is a revised edition of Part I of a report of the same title first produced in 1974.

The material has been enlarged and re-written to include developments since that year.

The purpose of the work remains unchanged - that is to record the author's experiences in developing the coursework of Design 3 (Mech.) devoted to the description of the creative process, and student experiences in trying to apply creative effort.

The rationale behind the coursework is described and typical design studies are listed. Some of the studies are analysed to an extent enabling student performance to be assessed. A scheme for the logical assessment of creative design work is proposed and criticised.

The final comments have been amplified in the light of the author's more recent experience, and his slowly developing understanding of the creative content of man's work as an engineer.

2. INTRODUCTION

The education and training of professional engineers is by no means so well defined a business that the last word has been said. Over the years it is noticeable that engineering curricula have expanded to include more topics than the available time can contain. Content and presentation are continually under review. Contemporary advances in technology seem to be reflected in the fashions for topics of study.

It does not follow that the successful cramming of new topics into the curriculum automatically improves the education of the student engineer. The imparting of knowledge alone is not the sole or even the principal objective of a school system. Exercise of the intellect deserves the major consideration of the faculty staff.

The precise amount of emphasis placed upon aspects of the retrieval of background information, knowledge of the sciences and of technology, of the intellectual techniques of inductive and deductive thinking, of analysis and synthesis, varies between universities, faculties and departments; and this is to be expected. However, the actual skills of intellectual reasoning are seldom taught as such - students pick up facility by indirect means. The educated and humane person develops more by absorbing his intellectual development than by actual exercise in specific mental abilities.

In a belief that the ability to carry out thought processes in a creative manner has always been an asset to the professional engineer, it has seemed logical to include some attempts to encourage it within the undergraduate curriculum.

Since 1964 some study within the syllabus of the engineering design courses at the University of Canterbury, Department of Mechanical Engineering, has been explicitly arranged to do this.

It is conceivable that the future demand for engineers will tend to favour those of imagination as well as the more usual abilities. The places available (in industrial management especially) for the mediocre will be a lot scarcer. It has been considered important, therefore, to ensure a reasonable content of 'creative design' and to make it suitably demanding.

With the experience gained during successive annual attempts to provide this creative content, certain definitions have been formed, and certain 'truths' agreed upon:

(1) What is "creativity" in the context of engineering? Creativity is that intellectual ability which results in original and worthwhile ideas for elements, machines, processes and systems to satisfy the legitimate needs of people. Such was an early effort; later a new approach yielded this parallel definition:

> Creativity is the intellectual power behind purposeful practical ingenuity.

(2) There is a characteristic and fundamental difference between the process of thinking in a creative (divergent) manner, and that convergent form of thinking associated with the implementation of the classical experimental method, in the search for truth.

(3) Academic studies have come to be regarded as synonymous with scientific analysis of phenomena. The analytical thinking involved is identified with scholarly erudition. It seems to be forgotten that the models of situations and phenomena set up for analysis are often the result of insight - itself the end product of much creative thinking, frequently more arduous than the subsequent analysis. The

curriculum is increasingly occupied with such scientific analysis. Where insight has occurred and enabled analytical tools to be applied effectively and thus extend knowledge by a quantum leap - its creative genesis goes largely unrecognised.

(4) Analytical methods can be taught as step by step logic. Creativity cannot be taught so explicitly but one may impel students into situations where they are challenged to be 'creative'. They must turn therefore to synthesis, call upon imagination and exercise ingenuity in a purposeful way.

(5) Response to challenge is a function of personal motivation. In so responding the student develops understanding and, eventually, insight. Not only does he stretch his imagination but he develops his character as an educated person.

(6) Original work, the product of creative thought shows characteristic insight, recognisable as imaginative, ingenious and apt. It is purposeful in that it satisfies a need in an optimum economic way. Such work cannot be assessed on the same basis as is scientific work of an analytical nature.

(7) Much research has been done to try to find an absolute measure of creativity or talent for creative work. This might take the form of a 'profile' of distinct personality traits, attitudes and abilities preferably free from an engineering bias, so that it might be validated with reference to all forms, and fields of man's creative work. Thereby we may hallmark creative people. In the field of engineering design - as also in the fields of the other arts, finer and coarser - we may prefer to measure the extent of a person's creativity by assessing the products of his intellectual endeavours. By his works shall we know him!

This short study represents an attempt to assess student performance in creative design work.

Part II of the 1974 report compared student performance on all the topics studied presenting correlations of assessments and commenting thereon. This will be revised and rewritten as a separate report.

3. MECHANICAL ENGINEERING DESIGN AT CANTERBURY

The author has reported before on the syllabus obtaining during the undergraduate years here (1). Since then he has been increasingly concerned with the final year - Engineering Design 3.

The final year course has been developed by successive increments each year so that significant topics are distilled into the limited lecture and coursework time. Appendix A is a copy of the syllabus for 1979.

The most significant development since 1974 has been the introduction of case study material and its use on a more demanding scale. From being general background, cases are now being used as significant coursework material upon which assignments are based and graded. This has had the effect of broadening the scope of the course and allowing other designers and engineers through the medium of their reported work as in the case material, to speak for the profession and to epitomise the design process, as it really is, by their behaviour. To some extent this has linked Design 3 with the parallel coursework of General Studies - 'The Engineer in Society'.

The author has thus been able to use his scarce lecture time to guide students in their assignments as well as their design studies so that a more comprehensive study course becomes manifest. It is now possible to present a graded introduction to the science and art of design, and then guide students' reading to show by example where science has been the basis and/or where the designer has functioned intuitively using his past experience and a sense of engineering style.

Latterly the illustrated design process has been described in "systems" terms, and the technical significance of "purposeful behaviour" in the context of design has become apparent.

The introduction to innovation in engineering and the role of creative thinking in engineering design remains the coursework of the first term of the final year. Case material has been particularly valuable here. It is the work of this first term that this report is principally concerned with.

To some extent, this emphasis on creativity has influenced the philosophy in the preceding two years. However, it has more 'power' in the final year where some substantial background of knowledge of engineering science and technology, and a modest level of 'practical work' experience have been attained by the students and can be called upon as 'matrices of experience' and principal design resource material.

It should here be noted that the trend of the last few years to introduce more engineering science into the early years syllabi and so exclude the corresponding technology will have a constraining effect upon design resource material. Visual appreciation of the customary hardware is a valuable source of inspiration when called upon to create machines and elements. The data bank of well known ways to construct machines and structures - as well as an appreciation of typical performances of prime movers and machines is necessary resource material. Knowledge of the science alone is not sufficient.

The 5 day design examination remains in use as a final design project for the student. The task of selecting a range of suitable topics as well as that of assessing and grading the resulting work is probably at least as demanding as the examination itself!

It has been customary to rate the coursework as of equal weight with the 5 day examination in determining the overall grade of each student.

4. THE RATIONALE OF THE STUDY OF CREATIVE DESIGN

Creation begins with insight, the result of the purposeful manipulation of concepts. It is the most powerful intellectual tool of progress, culturally and materially.

Creative work is very much a personal thing. Recognition of this in the field of engineering has not always obtained. One of the best reasons for encouraging creative talent in any field is to be found in the ultimate personal satisfaction and fulfilment successful creation affords to the individual concerned. Although the preliminary work is arduous, the ultimate success is particularly rewarding.

In engineering the creative persons are those who will be responsible for innovations not only of 'hardware' but of attitudes, policies, systems and techniques, which, taken together, lead to the responsible exploitation of resources, and change in the environment. The leverage these people may exert upon social conditions is of such a potential impact that it becomes desirable to identify them at an early stage in their career and provide the opportunities for development of their talent, and its use in a constructive or ethical way.

Identification of potential creative talent remains an extremely difficult task. Once a person has created then evidence of his talent is manifest and may be assessed.

What qualities of personality and attitude of mind, what level of intelligence and relevant abilities are requisite, to make up a profile that may be accepted as pertaining to a creative person?

From some of the literature - notably MacKinnon (2), Guilford (3) and Getzels and Jackson (4), an outline of the creative person emerges. A certain minimum level of intellectual awareness (intelligence?) is a prerequisite to the exploitation of creative talent. Persons of creative ability do show such aptitudes as: curiosity (high motivation), numeracy and verbal fluency, spatial ability, fluency with ideas, willingness to tolerate ill-defined and ambiguous situations, and self sufficiency. No one person shows all of these attributes to the same extent, but they do remain characteristic, and taken together describe a remarkable character.

A major objective of any course of study of creative design is to encourage such 'remarkable characters' to emerge from the mass of embryo engineers, and to accept that their talent for creativity may eventually find fulfilment in the profession.

Hence the challenging aspect of the Design 3 coursework described herein; in conjunction with the core material study; which may enable the student to see how he rates as a designer and fits into the professional scene.

The effectiveness of the challenges that may be employed - in the guise of 'design study' - will be increased as knowledge of what exactly constitutes the act of creation and the process of thinking creatively, is developed.

5. TYPICAL CREATIVE DESIGN STUDIES

These are presented as experiences of a 'need' requiring fulfilment as a matter of professional duty.

As a result of experience there may be identified some desirable characteristics, common to all such design studies.

(1) The need as expressed should require some re-defining - or thoughtful re-structuring, in order to expose the real need. The design situation has to be explored to become familiar ground. The state of the art has to be appreciated as well as the state of the customer.

(2) The real need, once defined, should represent to the designer a difficult goal to achieve in the available time. The solution of the problem posed should not be immediately obvious. Alternative courses of action should become apparent.

(3) Whatever the topic of the study happens to be, it is desirable that it should offer a challenge to the imagination, provoking the designer to seek a solution thereby keeping his motivation at a high level. In the engineering sense it should represent a socially worthwhile task, engendering a responsible professional attitude.

Table 1 lists some typical studies that have been used since those mentioned in reference 1 (1963).

The amount of interest aroused seems to depend on matching the intrinsic appeal of a topic to the personality of the student concerned. To this end a selection of between four and six topics is always circulated, giving a week in which to make a choice. It is considered important to try to get as many students as possible so motivated as to be emotionally involved in the search for ideas for solutions to the design problem.

Experience has shown that, during the week allowed for considering a choice, there will be one (or more) person who puts forward some personal scheme he wishes to pursue. If this seems likely to be compatible with the objectives of the course then he is encouraged to make use of it, e.g. item 24 of Table 1 was proposed by a student who had been recently engaged in the business of harvesting asparagus.

Another special study, initiated by a more than average knowledgeable student, was an agricultural aircraft design for New Zealand conditions. A foundry manager taking his degree at a mature age proposed and pursued a feasibility study for a special sand handler/conditioner for his works.

Some topics have proved to be more useful than was at first considered likely, e.g. No. 6 of Table 1 which reached the experimental stage, No. 13 which was constructed, and Nos. 18 and 20 which developed far more alternatives than was ever contemplated.

It is not sufficiently appreciated that creative thought takes time - often a very long time. For these studies a period of reflection time after the starting date is allowed. By holding regular tutorials so as to gauge the progress of each student group, it is possible to judge when reflection time has reached a reasonable length. In conjunction with the lecture material, the background reading and the case material, it is possible to encourage idea generation, and to emphasise the value of ordered thinking - the use of techniques and above all the separation of synthesis and analysis - or idea generation and evaluation.

The tutorial sessions have always been regularly scheduled, yet it has been noticeable that some students do not seem to be able to operate within a group, but prefer to arrange to have individual sessions. Evidently this enables some to open out and talk about their ideas more freely.

TABLE 1

SOME TOPICS USED AS CREATIVE DESIGN STUDY - 1964 - 1978 INCLUSIVE

1. A machine for applying 'mouth to mouth' resuscitation.
2. A man-powered soil tilling machine.
3. A mobile crane/manipulator for use in the Department of Mechanical Engineering workshops and laboratory.
4. A press with versatile control for research into deep drawing operations.
5. A self-contained unit construction environment conditioner for a house.
6. A man-powered rice planting machine.
7. A hand-operated stair climbing wheel chair.
8. A special hospital bed and support system for badly burned patients.
9. Replace the conventional motor car with a cheaper transport system.
10. A device to balance wheels automatically whilst in service.
11. A railway bogie with facility to adjust its wheel gauge.
12. An eating device for an armless person.
13. A load measuring platform for high jump athletes.
14. A tree pruner for the N.Z. Forest Service.
15. A unit design for a solar heating and air conditioning system for a typical Christchurch house.
16. A two man power unit for a man-powered aircraft.
17. A domestic butter preserver and conditioner.
18. A dispenser for cornflakes.
19. A landing and take-off platform for bird flight study.
20. A humane animal trap.
21. A transport system for Ross Island, and vicinity, Antarctica.
22. A library index card cutter/stacker.
23. A beach cleaning machine.
24. A cutter for harvesting asparagus.
25. Wool pelt holding and handling.
26. Utilisation of domestic wastes.

27. Energy absorbing motor car bumper.

28. A machine for picking mushrooms.

29. A weighing device for use in spac_ flight laboratories.

30. A bilge drain pump operated by ship's movements.

31. A man powered lawn mower capable of cutting up to a wall or building.

32. A movement damper to assist spastics to control arms and hands.

33. A simple and inexpensive device "to enable chains to be fitted to the wheels of cars when road conditions demand their use, so that one need not grovel on the roadside surface, nor get one's hands and knees dirty in the process".

34. A device to assess tool wear in a machine tool.

35. A pair of 'kitchen scissors'.

36. A motor cycle powered and mounted post-hole digger.

37. A silencing device for the ventilating fans in the Mechanical Drawing Office.

38. A container for the storage of potentially dangerous chemicals about the house to keep them safely away from children.

39. A simple and robust power generation system that shall be particularly appropriate for the island people of the Pacific Region.

40. A wheelchair 'dynamometer' for paraplegic athletes.

6. SOME DISCUSSION IN DEPTH OF THE CREATIVE WORK OF 1972 and 1973

CREATIVE DESIGN 1972

During the first term of this academic year students were required to undertake two such studies. The first was current from Friday, March 3rd to Wednesday, March 29th, which allowed 3½ weeks, comprising 24 timetable hours and 4 tutorial periods. The study had to be selected from the list shown in Table 2.

The second study was current from Wednesday, April 5th to Friday, April 28th, allowing exactly the same duration, timetable hours and tutorial periods as for the first. The study was to be selected from Table 3.

It will be noticed that some topics have been repeated from Table 1 but, in general, no study is repeated in immediately successive years.

The cornflakes dispenser and the humane animal trap were repeated because they proved to be so stimulating.

Experience has shown that to require two creative studies to be undertaken in the one term is unlikely to allow sufficient time for a thorough study of the relevant background, and for 'incubation' to take place. It also precludes the possibility of experimentation and prototype or model construction.

It should be noted that the 'Dog Exercising Machine' topic was given before de Bono's book (5) recording the results of his own study reached the New Zealand market. A comparison of de Bono's and Canterbury ideas on this topic is given below.

TABLE 2

CREATIVE DESIGN STUDIES 1972/1

Select your first study from this list:

1. A door for an Anechoic Chamber. (2)

2. A cornflakes dispenser (19)

3. A humane animal trap. (21)

4. A dog exercising machine. (18)

& 5. A metering and mixing device for a study in the transport of solids in a fluid. (2)

NOTE: The figures in parentheses indicate the number of students choosing each topic.

TABLE 3

CREATIVE DESIGN STUDIES 1972/2

Select your second study from this list:

1. A lifting device for a paraplegic. (2)

2. An individual propulsion system for a SCUBA diver. (17)

3. A device to utilise the energy of sea surface movements. (12)

4. A device to utilise the energy of direct solar radiation. (8)

5. A device to utilise the energy of the natural wind. (10)

6. A packaging and display system for a set of fragile consumer items. (5)

& 7. A dust excluding breathing apparatus. (1)

NOTE: The figures in parentheses indicate the number of students choosing each topic.

SOME NOTES ON THE DESIGN STUDIES SUBMITTED IN 1972

THE CORNFLAKES DISPENSER

1. The intractable nature of the material to be handled demanded that pains be taken to consider in detail its possible behaviour when dispensed by some machine. Problems of jamming between moving surfaces, 'bridging' in hoppers, crushing to dust, and loss of crispness with time, and etc.

2. The ability to sketch carefully - to scale - and to consider the implications of small changes in the geometry of the device, became obviously valuable.

3. Experimental studies, even simple and crude, provided they were well chosen, gave a lot of specific information. The readily available cornflakes, and the use of cardboard for hoppers etc. make this study useful. (Note - The lack of time for the project restricted experiment considerably. When given previously a lot of experimental study was carried out - see photographs attached. Figures 1 to 4).

4. Vibratory assistance to the flow was considered by some designers, but nobody thought to make deliberate use of the 'bridging' tendency of cornflakes and then regulate flow by vibration alone. Too many designs were based on the assumption of 'free flow' with no assistance.

5. An interesting analysis of the rationale of the existing packets was given in several cases. One fascinating suggestion was that the inconvenience of use of the existing packets provides a useful ritual - i.e. a kind of psycho-therapy at the breakfast table! Some careful detail design ideas were applied to existing packets.

6. At the other extreme were proposals for comprehensive fully-automatic machines to dispense, fill plates, and convey to the dining room either in rapid succession, or simultaneously in groups.

7. Types of designs proposed.

    a. Gravity Feed, regulated by:

        1. Sliding gate - 14
        2. Rotary valve - 12
        3. Double cone - 1
        4. Multiple slides - 4
        5. Trapdoor - 7
        6. Chute - 6

7. Tipping Hoppers - 2
8. Pusher type valve - 4

Vibrating assistance was suggested in four cases.

b. Power driven systems:

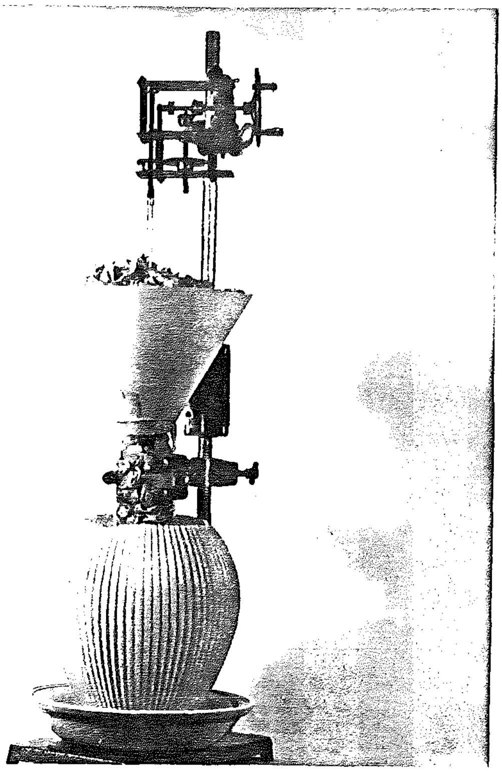
1. Conveyor belt - 1
2. Auger screw feed - 2
3. Sliding gate - 1

c. Hand-operated feed and control:

1. Rotary cup or scoop - 1
2. Bucket dredge or elevator - 2
3. Auger or screw - 3
4. Rotary vertical chamber or drum with partitions - 5
5. Conveyor system - 4

d. Modifications to existing packets so as to combine packet and regulated feed device - 6.

NOTE: The figures show frequency of each proposed design.



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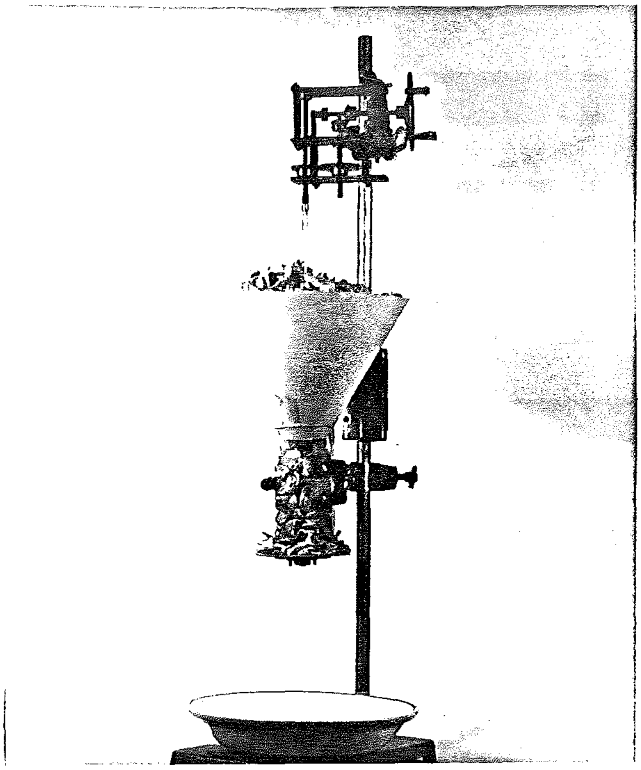

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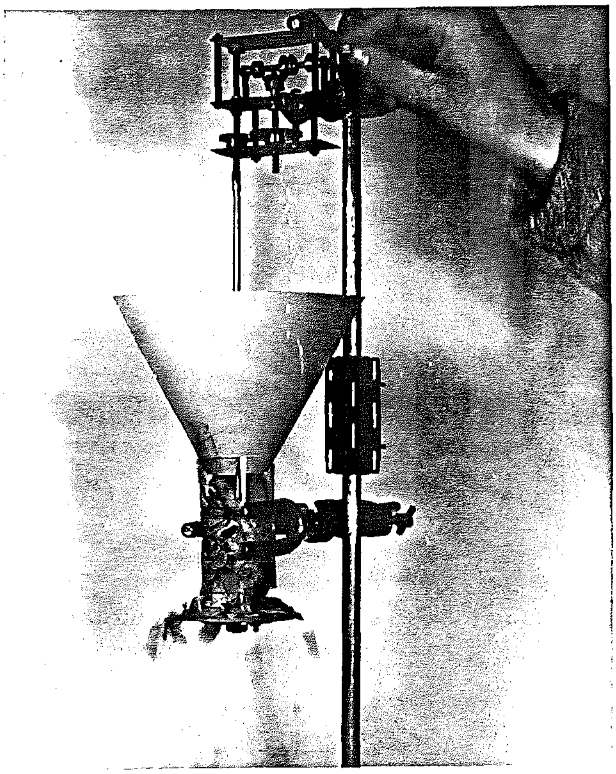
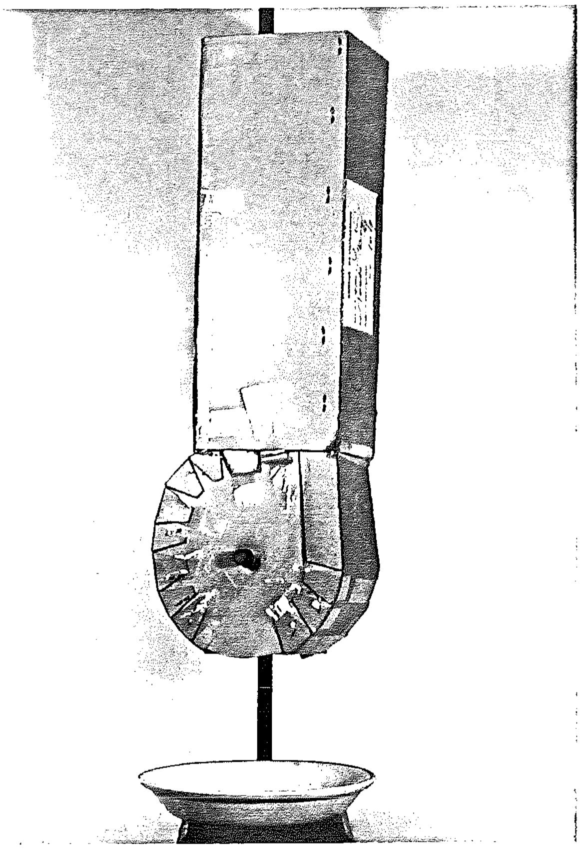


3.

Fig. 1 Motor-operated centrifugal cornflakes dispenser (1969)



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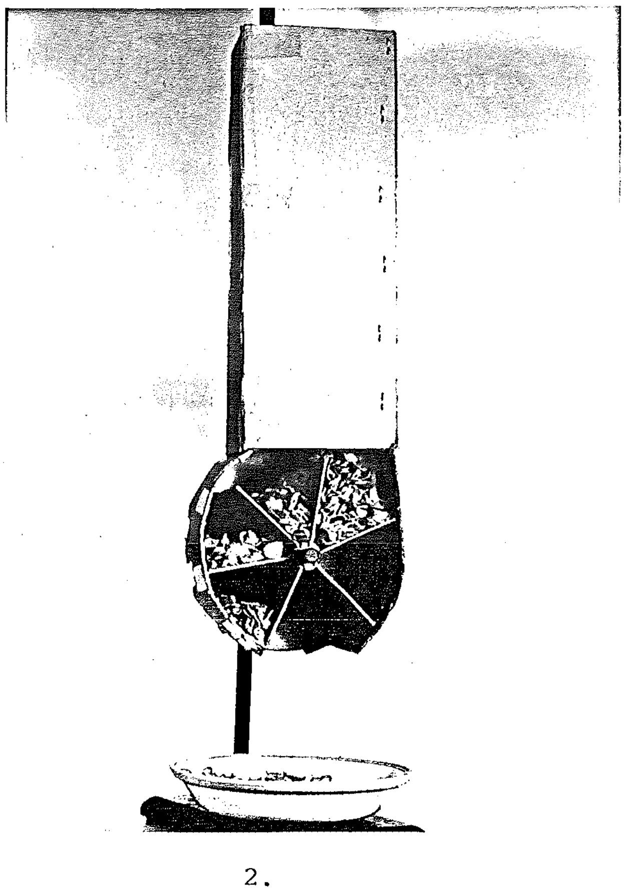
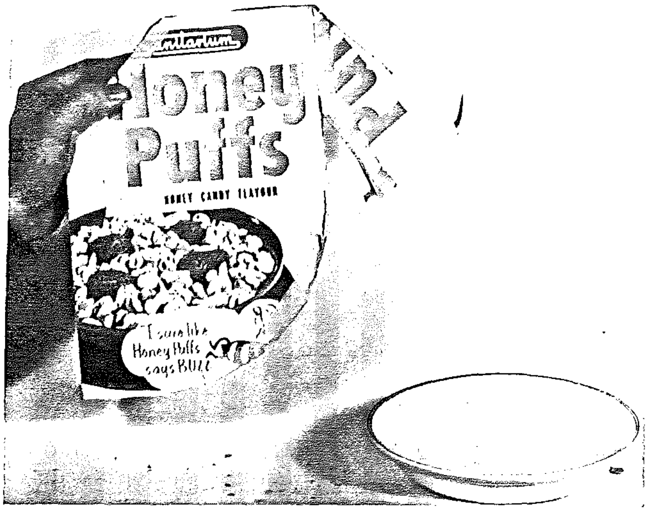


2.

Fig. 2 Rotary valve type cornflakes dispenser (1969)



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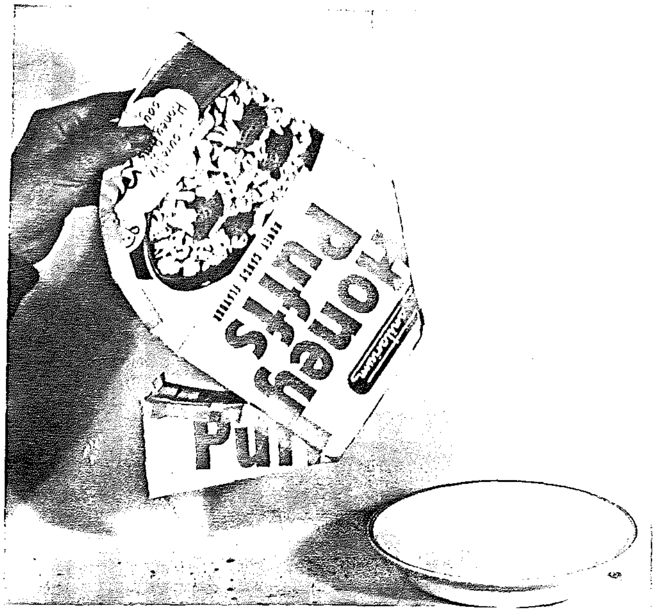

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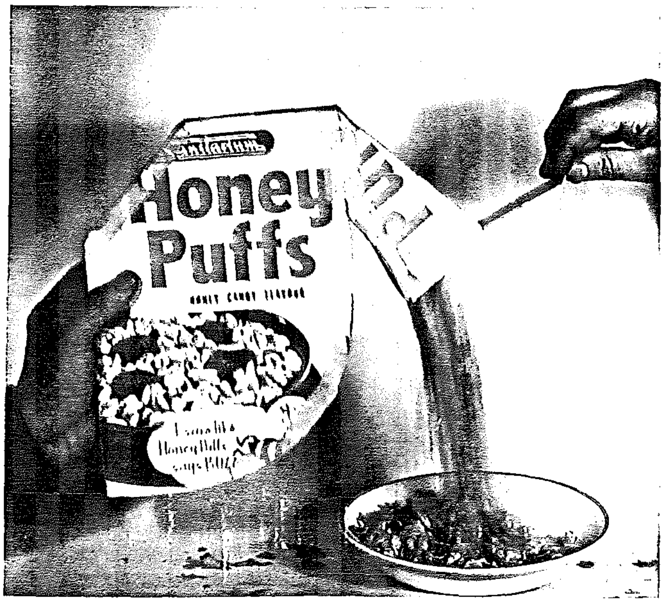


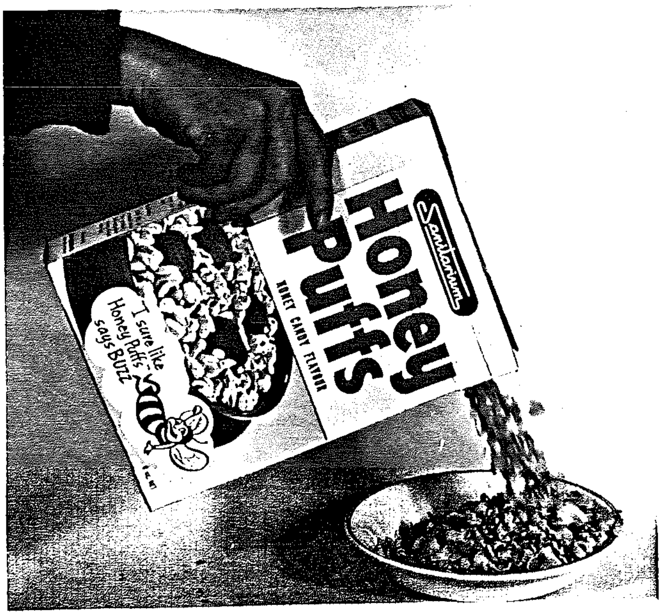
3.

Fig. 3   Modified packet type cornflakes dispenser (1969)

1.

2.

3.



4.

Modified packet design for a cornflakes dispenser (1969)

THE HUMANE ANIMAL TRAP

1. Briefly, a trap was required to be humane and sufficiently cheap and reliable to supercede the 'gin' trap currently still used in New Zealand. (1974)

2. The expressed need is so vague that a determined effort is necessary to develop some preliminary factual background data - e.g. what size and weight of animal? A decision becomes essential quite soon in face of much uncertainty, in order to begin to generate useful ideas.

3. Probably because of this, too many designers mixed up their creative work with its evaluation and as a result a good deal of mediocrity obtained.

4. Two distinct types of approach became apparent:

    a. The woodsman - using indigenous material on site in the bush.

and b. The mechanic-devising machines using the scrap and junk to hand.

5. The 'do-it-yourself' approach, however, is soon seen to be sterile in this context, because such a philosophy will not compete commercially with the available 'gin trap'.

6. During tutorials an interesting parallel became apparent between the real need here under investigation and the urgent problems due to overpopulation of earth by mankind.

7. Two designs only seemed to come within reach of fulfilling the specification out of the many described below, namely g and h.

8. It was noticeable that this study provided excellent practice in the use of 'order of magnitude' calculations and successive approximation towards the design goal.

9. Some types of trap design proposed:

    a. Modifications to the gin trap try to alleviate its notorious inhumane features - 12.

    b. Adaptations of the towel holder and spring leg type of trap (Viet Cong Pattern!) - 5.

    c. Box-cage - opossum type trap and mods. - 9.

    d. 'Lobster pot' cage trap - 2.

    e. Pit in ground with and without trap doors - 10.

f. 'Hollow tree' - 2.

g. Net(s), sprung over animal, or animal caught up in a net - 15.

h. Animal rolled and retained in a net or cage of wires - 4.

i. 'Spring up' type of cage - 6.

j. Poison or drug administered by a trap - 6.

k. Gas used similarly - 2.

l. Animal killed by a knife or club impelled by a spring - and variations - 13.

m. Snare and developments of same - 8.

n. Modified mouse or rat-trap - 4.

o. Animal retained by a glue or surface traction material - 1.

p. Electric shock to kill - 6.

q. Ultra-sonic treatment to kill - 1.

NOTE: A very simple device has now been proposed and accepted as an alternative to the gin trap - it is not listed above - and in the context of this study was never considered! However, although cheap in first cost it involves relatively high running costs.

THE DOG EXERCISING MACHINE

1. Extensive discussion over several sessions was held, about the identification of the 'real need' in the course of which a very wide range of situations in which dogs would require exercise (and the nature of that exercise) was examined.

2. Physical characteristics of dogs - (these were not so easily discovered as one might think), Psychology of dogs - here the tutorial group found itself on very thin ice! It was agreed that dog psychology was a necessary study, however, if any design was to be acceptable - to dogs!

3. Several different areas of requirement were identified:

   a. Professional - training and exercising of 'working' dogs.

   b. Play - for the average dog to improve the quality of his life.

   c. Remedial therapeutic, medical and research into dog performance and capabilities.

4. Designs proposed covered such things as:

   a. Treadmills - 9.

   b. Moving belt systems - 16.

   c. Moving discs set in floor - 4.

   d. Massage (vibratory) devices - 4.

   e. Wave motion (vibrating) floor devices - 1.

   f. Electrical stimulation device - 3.

   g. Running Tunnels, tracks - 12 (with a maze and/or mechanical rabbit).

   h. Rotating arm exerciser - 6, (some with a mirror, for company).

   i. Artificial environments, such as free range parks with trees! or a shooting range for master and dog - 3.

   j. A tank for swimming/washing with mechanical exercising devices too - 6

   k. The 'Sisphus' device - a sand hill to climb - 1.

   l. Stepping stones set across a river - 1.

   Spring hobbles for legs! - 1.

   n. Dogs' Squash Courts - 1, ball thrower and ball chaser box device - 3.

   o. A dog and child playground - 1.

p. Dog trampoline - 1.

q. A Dog pulling, digging, jumping machine - 3.

Some of these ideas have a definite sadistic content. Some cater solely for exercise of the dog's muscle system, - while others try to cater for the dog's interest, as a dog, including his need of companionship.

Ideas too could be divided into those which were small scale machines such as a. to f. above, and those conceived on a much larger scale such as i. which in one version, was intended to be integrated into the megapolis of the future when natural environments no longer exist.

During the currency of this study, apparently nobody could discover whether or not such a machine was in existence. Time did not allow an extensive search. It is interesting to note the successful use of a moving belt device in Australia, more or less as proposed in b above for the exercise of greyhounds. If any student was aware of this, he never let on!

De Bono in his book "The Dog Exercising Machine" (5) reports on a range of proposals put forward by children between ages of 4 and 14. This information was not available during the currency of the study at Canterbury, the book coming onto the New Zealand market later in the year.

A comparison in detail of the design studies by our students with those proposed by the children is hardly feasible since space does not permit. There are, however, some overall impressions:

a. Children's proposals are not inhibited by any mundane considerations of practicality.

b. Students' design pay more or less respect to features of practical and economical construction.

c. The basic methods of constraining dogs to walk and run by machinery seem to be as well comprehended by the children as the students. Engineering knowledge does not seem to have given them any advantage in ideas or methods. In fact from the greater range of schemes proposed by the children, an engineer designer could develop more food for thought than from the collected efforts of the group of students, e.g. a child's suggestion to operate an exerciser acoustically, by dog bark!

d. The children seem far more concerned about the dog's welfare, being prepared to supply him with more elaborate incentives to exercise, e.g. movie films of rabbits to chase, bottles of exciting 'smells', bones, meat, etc. Only one instance of punishment being arranged for lazy dogs is noticed - whereas as noted in (5) above, many student proposals handled the animals quite roughly.

e. Held in common, however, were the all round attractive ideas for child/animal recreation areas, running tracks, and artificial environments, sometimes designed to fit into the structural features of large buildings. Concern to achieve a contented as well as a fit dog was well appreciated. Comprehensiveness shown by the detailed and elaborate play parks of the children, was matched by a sophisticated and elaborate computer routine shown by a student, for the examination, diagnosis and treatment of all forms of dogs, physically and mentally.

f. The willingness of children to illustrate their designs, unhampered by any forms of drawing convention, contrasts markedly with the poor quality and inhibited aspect of too much of students' illustrations. One would not expect exactitude in mechanical detail from the children - although many of the sketches in De Bono show correct basic kinematics. From the students it would be expected, but few took pains to show the detail of a device providing relative motion, mechanical advantage, etc., despite previous training.

INDIVIDUAL PROPULSION SYSTEM FOR A SCUBA DIVER

1. In general the necessary background calculations involving the application of fluid dynamics, and the mechanics of flow and fluid resistance to motion were very poorly carried out. Inability to consider the effects of a range of variables, and absence of commonsense checking of results of initial calculations were very noticeable. The understanding of elementary fluid mechanics was poor throughout the whole tutorial group.

2. Ideas for energy sources alone were often given but a propulsion system is more than this! The full range of possibilities of combinations of energy sources, with schemes for producing thrust and control, was not closely approached.

3. This sombre picture was relieved somewhat by an enterprising group who actually towed a SCUBAdiver under controlled conditions in a swimming pool and produced a basic resistance/speed curve!

4. In this study, as in most others too, diagrams and sketches have to be good to illustrate and communicate quickly and effectively the sort of rather vague proposals dealt with. Especially is this true in the initial stages when ideas should still be coming along rapidly. Sketching ability was not good.

5. Some propulsion systems put forward:

   a. Back pack, with screw propellor, air motor or electric or jet - 10.

   b. Push pack on the feet - electric - 1.

   c. Pull-scooter, electric, air motor or jet - 16.

   d. Wet-mini-submarine, electric - 9.

   e. Dry mini-submarine, electric - 3.

   f. Mechanical bicycle and screw propellor - 1.

   g. Tow sledge - 1.

   h. Mechanical flippers - 1

   i. Mechanical jet using 'bellows' - 1.

   j. Pet dolphin (porpoise) - 1.

CREATIVE DESIGN 1973

Students were required to attempt only one study during the first term of the 1973 academic year. The period allocated was from Wednesday, February 28 to Friday, April 13, comprising 6½ weeks, 42 timetable hours, and 4 tutorial periods.

The study topic had to be selected from the list shown as Table 4.

It might be said that the beam design (Topic No. 5), was not a creative design study in the sense of those given in 1972, Tables 2 and 3, and in comparison, say, to topic No. 2 of Table 4. The duty to be fulfilled was quite clearly specified. However, the details of the means whereby that duty was met gave the scope for the exercise of ingenuity. The next section of this report describes some of the beam designs which were made and tested, illustrating the range of constructions involved.

Fears were expressed that the majority of the student class would opt for this design/make/test study to the neglect of the other alternatives. In fact as the figures in Table 4 show, this was not the case. Since 1973 this type of design study has been offered in 1977 and 1978 with very similar results.

TABLE 4

CREATIVE DESIGN STUDIES 1973

Select ONE only:

1. A vehicle noise assessment system for a testing station. (7)

2. A locking wire application for reinforcing steel networks. (16)

3. A solar-powered cooker/refrigerator. (10)

4. A solar-powered irrigation pump. (14)

& 5. A design-make-test study of a beam to carry a specified load over a specified span. (13)

Students were invited to submit their own proposals for creative design studies. This year one student did so, adding one more topic to the list:

6. A seedling box handling and filling machine for a market garden. (1)

Student proposals are not often received and are only adopted if considered to fit the pattern of design study required.

NOTE: The figures in parentheses indicate the number of students attempting each alternative study.

7. THE 'DESIGN-MAKE-TEST' STUDY

ORGANISATION AND ADMINISTRATION

At the first tutorial session the bare statement of the study was enlarged upon, the details being specified, as follows:

1. To design, construct, and test a structure to sustain a load of 2000 lb. at the centre of a span of 30 inches, and at a height above the supports, of 12 inches, safely, for at least 30 seconds.

2. All loading points of application to be regarded as 'simple'.

3. The only materials permitted to be used in the construction being the hardboard and glue supplied by the department.

4. Schedule of work:

   a. All calculations, information and memoranda relating to the study to be recorded in the designer's workbook.

   b. The initial period of 3 weeks for the background study and design.

   c. A workshop drawing to be prepared with a complete Parts List. The weight of the design to be calculated. The failure load to be predicted and the mode of failure.

   d. Each completed design to be scrutinised and approved before construction will be authorised.

   e. The following period of 3 weeks for construction.

   f. Completed structures then to be weighed and all tested in one session. Results tabulated in the test laboratory for all to see.

5. Compliance with the specification in (1) above is the first objective. Weight, failure load, and mode of failure recorded to be compared to those predicted. A strength/weight ratio should be calculated.

6. A further week to be allowed for the preparation of a report. This to describe the design philosophy adopted, the actual performance of the structure, and to account for discrepancies between actual and predicted behaviour. A summary of the entire range of designs with a criticism is suggested.

7. Each student to hand in his design workbook, his drawing, and his report, all for grading.

SOME TUTORIAL DISCUSSION TOPICS

1. The geometrical limits to the structure and, in particular, constraints on its width. In effect, the volume within which the structure had to exist was defined.

2. The meaning and implications of a 'simple' support were examined. Discussion as to the manner of loading led to a careful examination of the machine in which it was proposed to test each structure.

3. The 'real need' was debated. Some students were content to see it as an exercise in the design of a structure to carry a load. Some preferred to define the need as the achievement of the highest strength/weight ratio. There was then debate as to how to define such a ratio.

4. Early trial calculations showed the need to develop knowledge about the strength of hardboard, and of glued joints. A few students led the way in the necessary experimental work, after attempts to find out the required figures from the manufacturers had proved unhelpful. The data resulting from several series of tests on hardboard, and joints of various configurations became available. It was not certain that all the students proposing to design structures had access to all the experimental results.

RESULTS. Figure 5 shows some photographs of the construction period. Figures 6 and 7 show examples of most of the types of structure made. These included:

1. Straight guiders - box sections and 'I' sections. Some with stiffeners, and full depth, others of smaller depth with a special pick up point for the load.

2. Tapered guiders - box and 'I' section.

3. Triangular frame with stiff joints - a few more elaborately designed to have hinged joints.

4. Arch shape, with 'bowstring' tie.

The greatest scope for ingenuity undoubtedly exists in the design of the joints. Especially in view of the nature of hardboard, and the restriction to a glue. Here creative thought was certainly exercised! In the case of structures with hinged joints, very careful attempts were made to reproduce the conditions that had been assumed in the previous design analysis.

Table 5 shows a selection of the results of tests on structures from all years.

EVALUATION

Student motivation was noticeably high throughout this study. Some may have chosen it under the impression it would turn out to be an 'easier' study than the others on the list, but once committed they accepted the challenges, and even overcame them!

The initial impression that a theoretical analysis using the well known theories of bending and shear in beams, would be straight forward and sufficient was soon dispelled. Problems associated with stress concentration at loading points and joints, with deformations, with buckling modes, and shear between flanges and webs soon arose.

In many cases a lot of work went into the design and the subsequent construction.

Table 5 indicates that many of the designs failed at loads far below the specified 2000 lbs.

Many of the designers became quite seriously involved when before their eyes their structure so carefully made failed in a manner unforeseen. The lessons of such failure are dramatic, and often hurt.

Their design reports frequently included quite extensive 'post-mortem' analysis to determine the cause of such premature collapses.

It may be said that this kind of design study was generally successful as presenting a microcosm of engineering 'practice'.

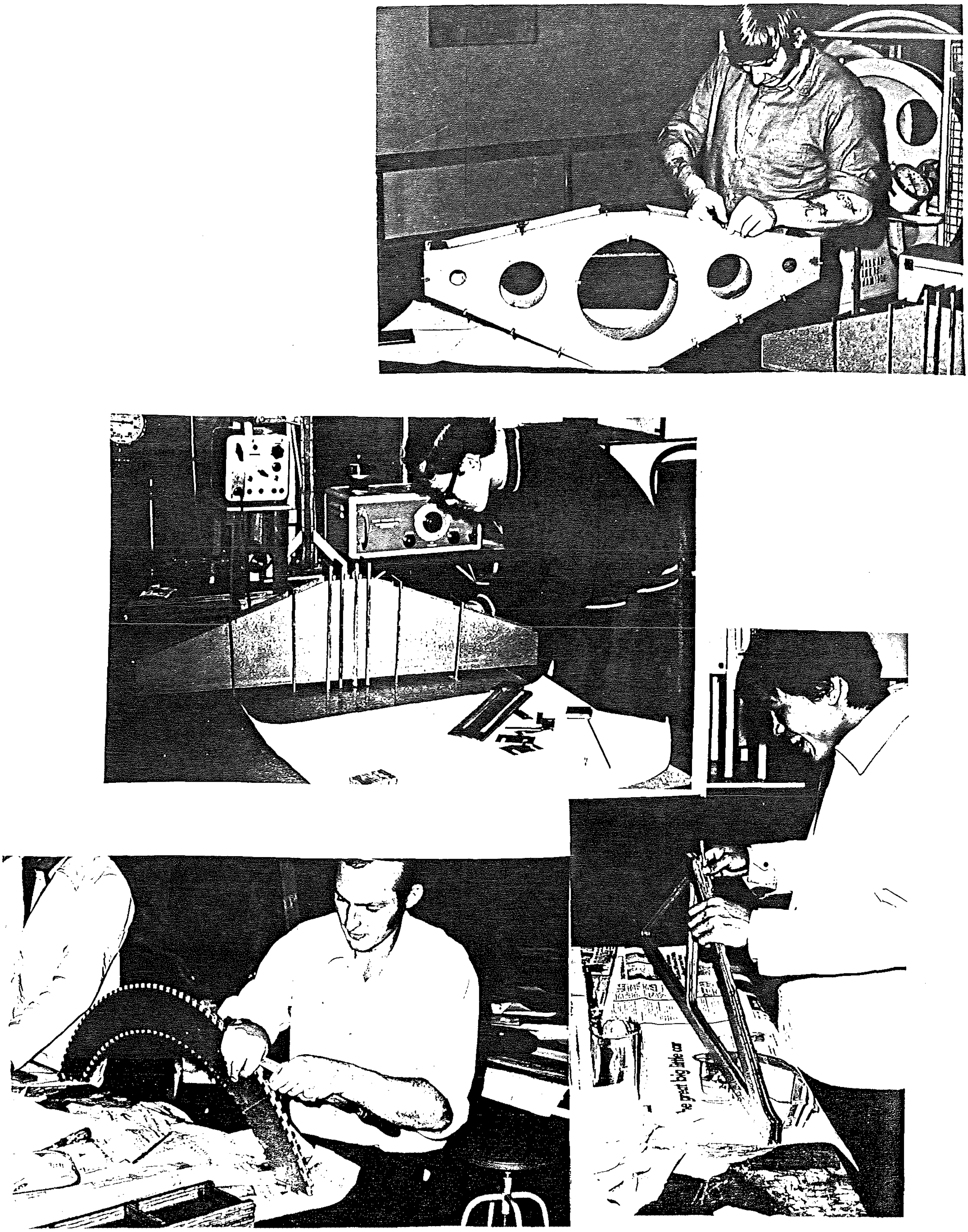
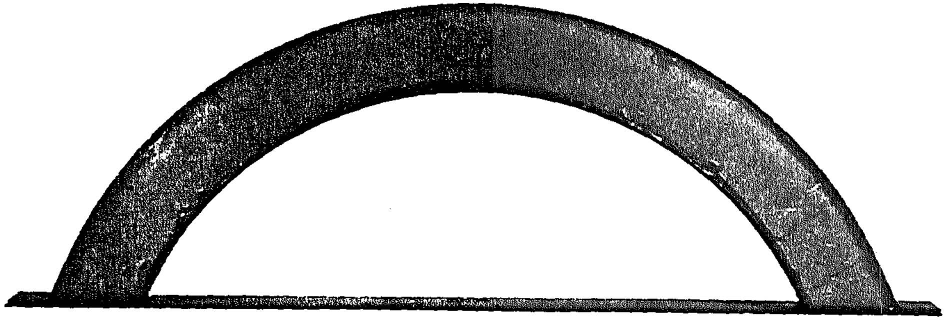
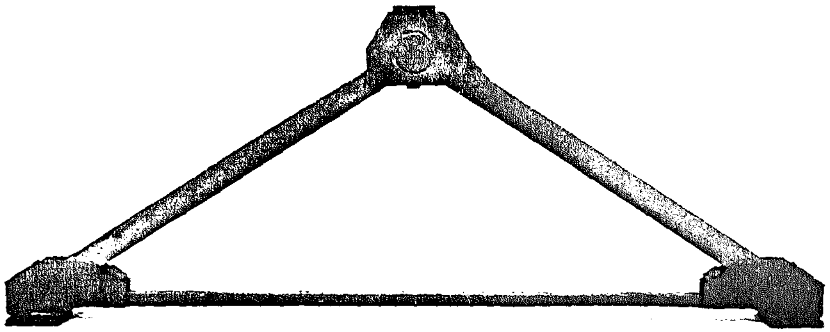
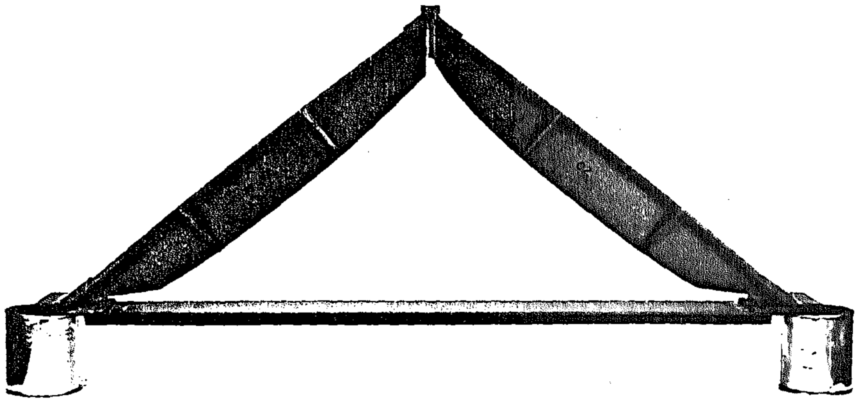
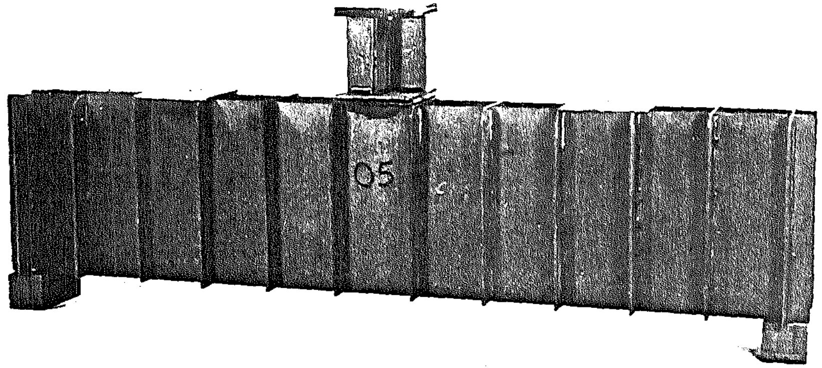
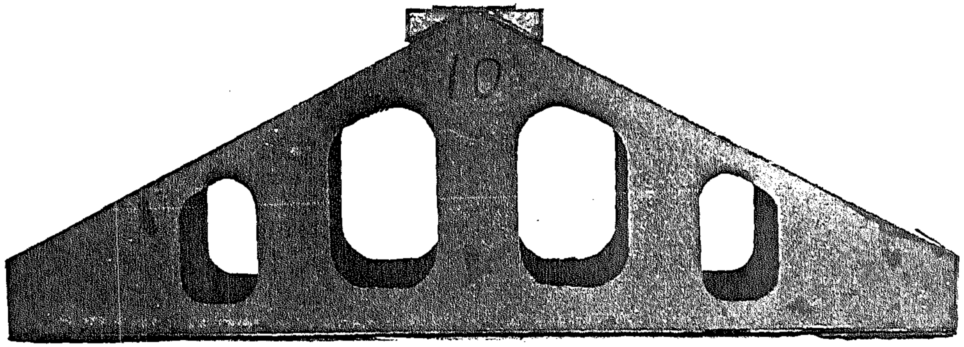


Fig. 5 Some structures under construction



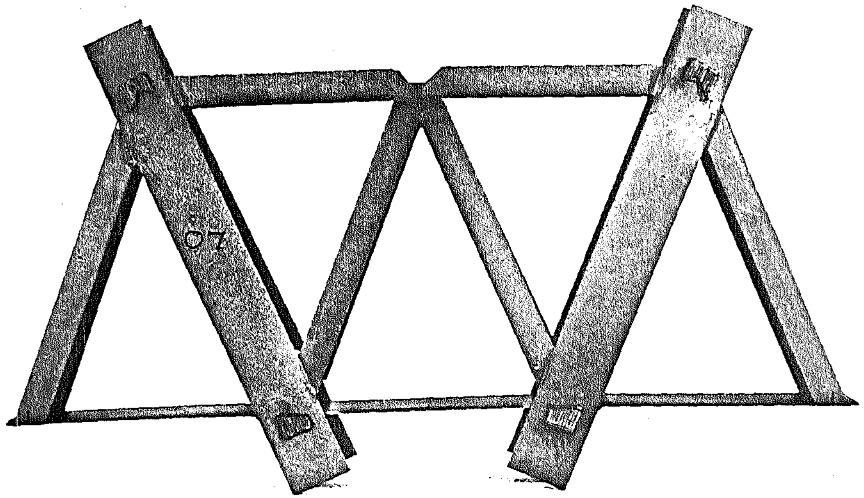


Fig. 6 Structures 1977

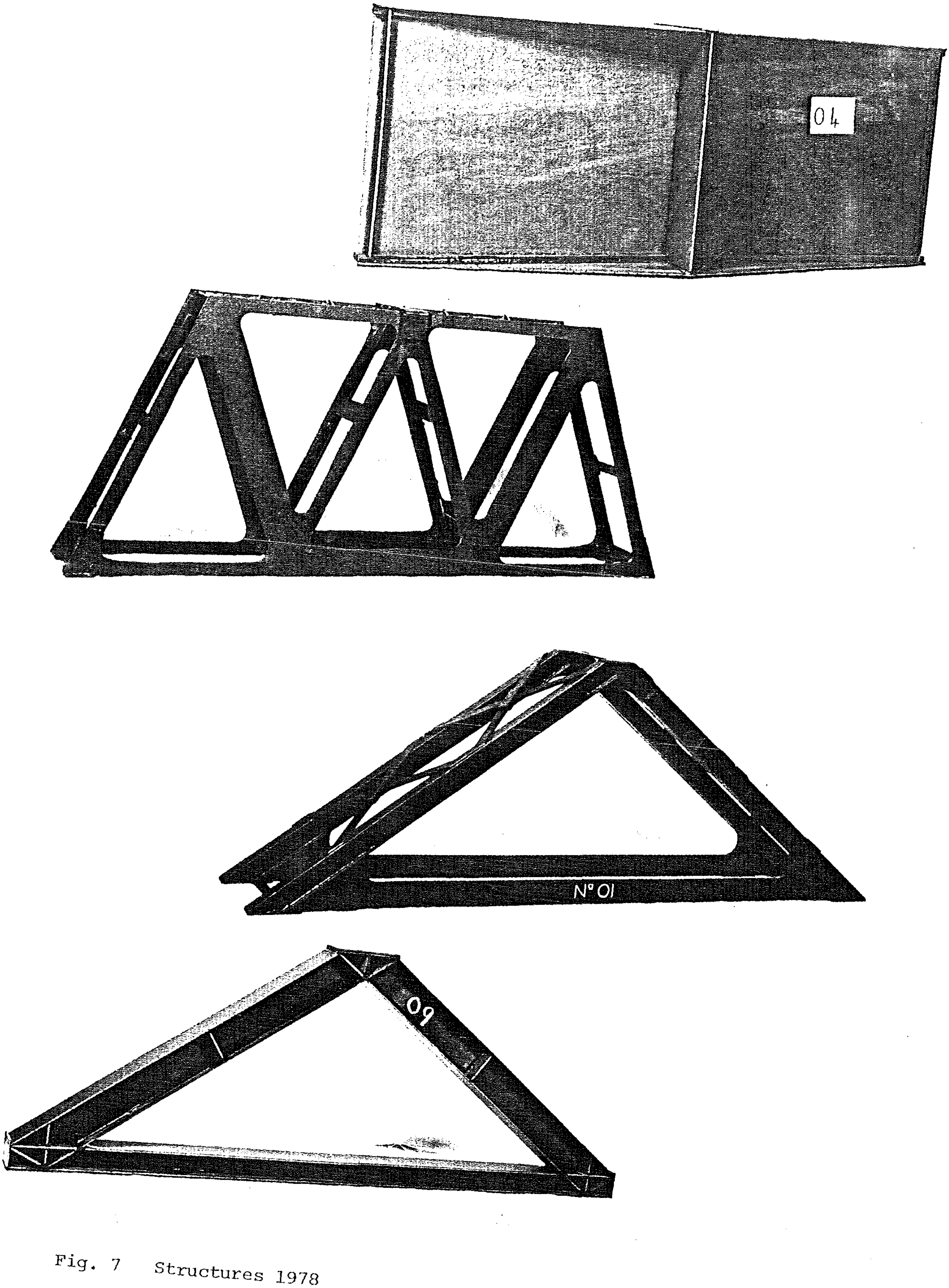


Fig. 7 Structures 1978

Structure No.	Weight lb.		Failure Load lb		Mode of Failure		Failure Load lb. / Weight lb.	Design Load / Failure Load
	Predicted	Measured	Predicted	Measured	Predicted	Observed		
02/77 See Fig. 6)	1.75	1.82	2320	1380 Y 1715 F	Joint Compressio n	Twist Buckling	942	1.17
04/77	1.60	1.29	2000	720	Strut Buckle	Joint Fracture	558	2.78
05/77 See Fig. 6)	3.00	2.06	2200	875	Tensile Bottom Web	Tensile Bottom Web	426	2.28
08/77	2.48	2.38	3000	1685	Strut Buckle	Strut buckle and shear of glued joint	709	1.19
13/77	2.27	2.00	2500	170 Y 300 F	Tensile Bottom Flange	Severe torsional buckling	150	6.67
04/78 See Fig. 7)	3.90	3.60	2000	1300 Max. 1240 F.	Shear between web and flange	Web Buckling	344	1.61
08/78	2.88	3.06	2200	2200	Tension in lower joint	Leg Buckled	717	0.91
10/78	3.31	2.60	2500	1760 Max. 1640 F.	Tensile or bend failure of horizontal member	Adhesive failure in compression leg	630	1.22
11/78	3.25	4.08	2500	3000+ (not fractured)	Failure of 'leg'	Legs buckled	735+	0.67

NOTE: Y = Yield F = Fail.

TABLE 5. A Selection of Structure Tests

8. ASSESSMENT OF CREATIVE DESIGN STUDIES

1. Ideally a complete record of the history of the individual designers conscious and sub-conscious mental processes throughout the study is required - properly to assess the scope and depth of the work.

2. Where it is possible to hold frequent tutorial discussions as between 'Master' and 'Pupil' then some approach to the complete record may be made. More usually with the student numbers per topic indicated above, and the necessity to keep each tutorial within 45 minutes duration, no such completeness is possible.

3. The present assessments are made on written evidence.

   (a) the designer's work book which should contain ALL his notes and sketches

   (b) the presented design report and proposal.

4. These are the main items on which each study is graded.

   (a) The interpretation of the expressed need (or Specification) as given to the designer.

   (b) The number of ideas produced and the categories covered, i.e. the fluency and flexibility in the production of ideas.

   (c) The quality of those ideas, aptness, originality and relevance.

   (d) The evaluation of the ideas for feasibility

   (e) The decision as between ideas (or strategies) and the presentation of the choice.

5. The marking of each of these items follows this scheme.

   (a) Interpretation. This involves analysis of the expressed need in terms of the state of the relevant art. Credit is given for efforts to increase relevant knowledge to attain a more penetrating interpretation so as to be able then to perceive and to define the real need. A good test of this is that, "the real need can be defined without mentioning any specific means of fulfilling it".

Evidence of sensitivity to the existence of subtle problems not readily perceived by conventional minds, and a willingness to formulate them explicitly is rated highly. This amounts to a creative restructuring of the expressed requirement.

Mark to a scale of say 0 to 5.

(b) Ideas FLUENCY Assess each idea as representing a significantly different concept, e.g. "Cornflakes dispenser" page 14 above note paragraph (7) "Sliding gate" as distinct from "rotary valve", so providing thereby two "distinct ideas".

Whereas in the same paragraph note "Sliding gate" and "Multiple slides" which latter concept may be regarded as the same distinct idea as the former, but with variations on the basic theme.

The Flexibility score is taken from the number of "categories" into which the list of "distinct ideas" may be divided, e.g. page 14 again, note that paragraphs 7a, 7b, 7c, and 7d can be said to represent "categories" of ideas for the dispenser. Therefore ideas are scored for fluency and flexibility, as follows:

Fluency - Up to	3	distinct	ideas	- score 1
	4	"	"	- score 2
	5	"	"	- score 3
	6	"	"	- score 4
	7	"	"	- score 5

to a maximum of 5.

Flexibility - For each category into which ideas may be divided score 1 up to a maximum of 5, for 5 or more categories.

(c) Quality - Assess aptness in terms of economy of effort, materials and budget; originality in terms of statistical infrequency, and relevance as fitting the theme of the study. Take each distinct idea and rate it on a scale of 0 to 5 - as follows:

5 - Excellent, 4 - Very good, 3 - Good,
2 - Fair, 1 - Poor, and 0 - Hopeless.

Take an average score for quality.

Apart from the distinct ideas, the variations, on a theme, merit some rating, from say 0 to 5, scoring the least when they are closest to the original distinct idea. An average score for all variations should be added to the average score for quality up to an overall total of 5/5.

(d) and (e) Evaluation. This should feature as a separate issue in the scheme of work, and not be mixed up with the previous activities. Rate evidence of sensitivity to the outcome of each distinct idea put forward. The ability to develop a range of ideas (strategies) and foresee the implications and consequences of the adoption of each in turn in terms of some systematic survey of 'problems arising', is anticipated. Casual comment rates little or nothing. Consider any further evidence of sensitivity to subtle problems. Give credit for the use of a weighting system to assist in comparing alternatives for tractability. Hence assess the quality of the decision made and the adequacy of its presentation as a feasibility study in an engineering context.

Mark 0 to 5.

6. Overall Assessment.

To summarise, this will comprise the following:

		Possible
a.	Interpretation -	5
b.	Ideas - Fluency -	5
	Flexibility -	5
c.	Quality (including variations)	5
d. & e.	Evaluation and presentation	5
	Total possible score	25

It is suggested that:

Scores	20 to 25	- Highly creative
"	15 to 20	- Markedly "
"	10 to 15	- Some creative talent
"	below 10	- Not at all creative

EXAMPLE ASSESSMENT OF A CREATIVE DESIGN STUDY

Need A device to provide clean air for breathing in all types of dusty working conditions. Facial contact to be avoided, visibility to be unimpaired, and minimum chance of claustrophobia.

Context - Initially farm work under dry conditions often met on the Canterbury plains, but applicable also to industrial conditions. Assessment of the student's work book and presentation using the above described system was as follows:

1. Interpretation. An extensive and thorough analysis of the need was given, including some successive re-definitions. His discussion of his specification for a device was quite open-ended. Score 5/5.

2. Ideas - about isolation of man from the dusty air. Some ideas for system and some ideas about points of view to be taken on working conditions, etc.

Scores - 4 distinct ideas - 2./5.
3 categories - 3./5.

Quality of each distinct idea, scores.
1, 3, 4 and 5 - average 3.

Variations on the themes of the distinct ideas total 7, scores, 3, 1, 4, 2, 4, 1, 1 - average 2.

Total for quality - 5/5.
Total for ideas - 10/15.

3. Evaluation - takes in whole spectrum of dust problems as he has developed it above and makes a good evaluation with respect to feasibility, practicability and reasonable economy - not neglecting appeal to the user.

Decides, a. A policy of stopping the generation of dust at its source is to be advocated. (Hence further design studies!)

and b. To develop a face mask with air feeding as a design feature.

Scores 3/5 Grand total 18/25, i.e. a 'Markedly creative' study.

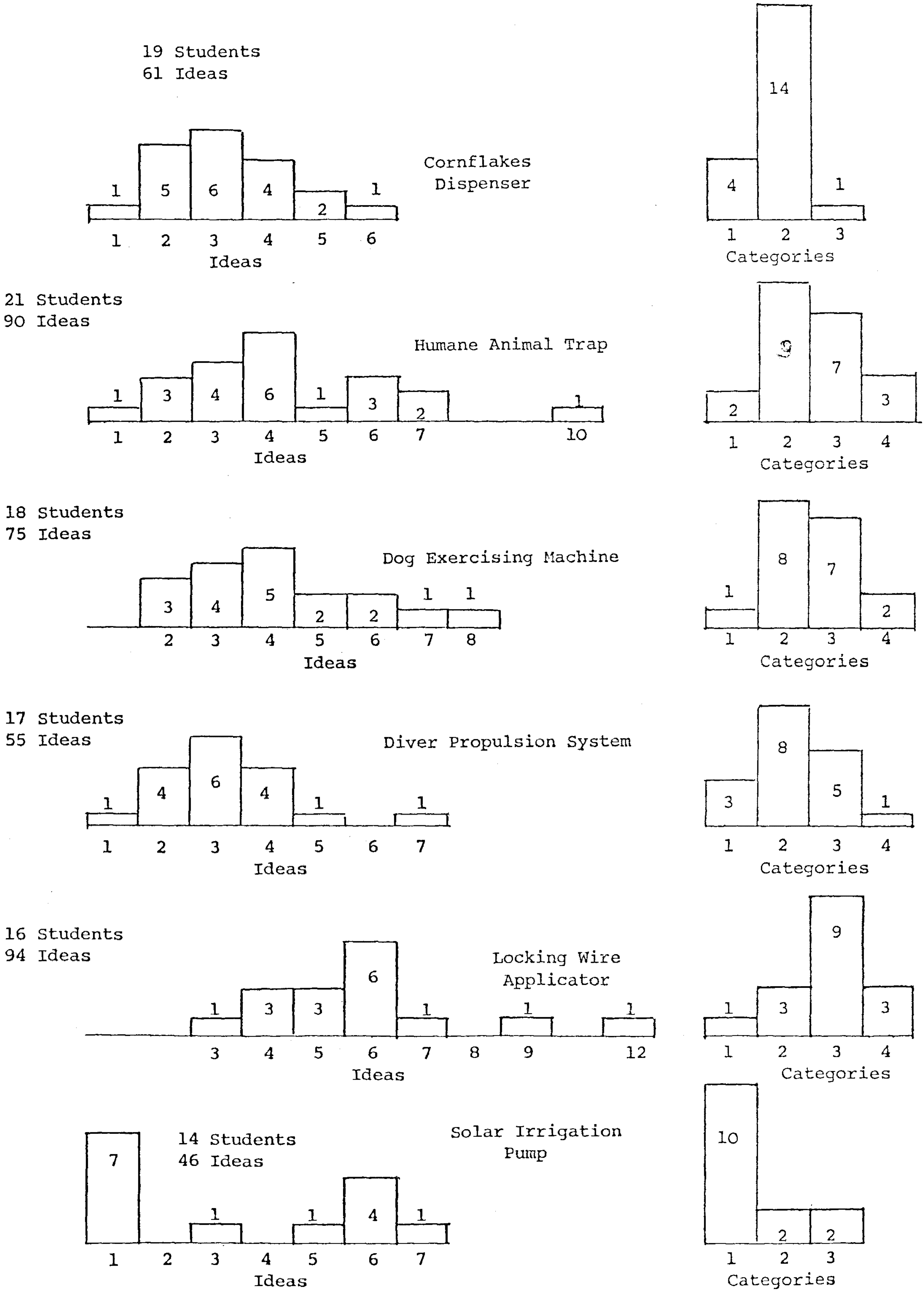


Fig. 8 Creative Design Studies 1972/73

Distribution of ideas

COMMENTS ON THE DISTRIBUTIONS OF IDEAS

1. A few students stood out as obviously more fluent and flexible. In each of the studies analysed in Figure 8, the student who put forward the largest number of distinct ideas, was also the one proposing the most categories.

2. There is little evidence in these data that the longer period of currency of the 1973 studies gave rise to significantly more ideas per student, or that the extra time enabled any one student to achieve an exceptional insight.

3. The extended period enabled one extra tutorial session to be held after the idea generating period was considered over. This permitted a more penetrating evaluation to be achieved, and the inherent value of deferred judgment could be better illustrated. For the design/make/test study, the extra time came after the agony of testing and the comparison of the several designs and their performance was exceedingly instructive for all concerned.

4. Time for the construction of experimental rigs and prototypes to test concepts in principle is most desirable as exemplified by the students responsible for Figures 1 to 4.

5. For many students the business of sketching is a slow and painful process. Where a study is undertaken of the nature of 'a locking wire applicator', sketching becomes vital to the communication of design schemes. Many of the proposals here were presented in sketch and/or prototype form - wire clips, etc. Without this time to work up their presentations the study would have been far less successful.

9. ACKNOWLEDGEMENTS

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10. APPENDIX A

UNIVERSITY OF CANTERBURY

DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN 3 (MECH)

SYLLABUS 1979

The Course comprises one formal lecture per week, two principal design studies, a series of case histories of engineering design, background reading, and a final design study as a 5-day examination project.

The lectures outline the course topics and provide a guide to the meaning and relevance of the case materials and the background to the philosophy of the process of design.

Students experience the design process by their own application in fulfilling the needs expressed by the studies they choose to undertake.

1. The nature of creative work and innovation in engineering.

Lecture topics	Coursework
Creative Thinking. Obstacles to Creation. Aids to Creation. The Role of Knowledge. A Theory of Creative Thinking. The Management of Creative People.	A creative design or feasibility study. 3 Case histories of creative work by individuals, as design engineers. 2 Assignments on these cases and associated reading.

The design process is here treated as though the designer operated in the fashion of a "black box". We know what goes in, and we see what comes out; but what happens inside the box?

The case material is studied in seminars and the understanding of this and the reading material is assessed by requiring assignments to be undertaken and handed in for grading. The creative design or feasibility study is chosen from a list of such studies and occupies most of the first term time.

2. Design as a systematic purposeful activity.

The design process is here seen as a logical and systematic attempt to take informed decisions and proceed in a purposeful manner through all difficulties to achieve the optimum solution to the design problem for the time being. The designer being considered as a 'glass box' so that we may appreciate precisely what he does and for what reasons.

The fundamental philosophy here is to take a model of the design process as a 'socio-technical' system (described by the theory developed by Ackoff & Emery); or "purposeful ingenuity".

Lecture Topics	Coursework
Aids to the analysis of the design situation. Optimisation Techniques. Decisions Theory. The nature of engineering decisions in management. Optimum design of machine elements. Optimum design of mechanical plant. The display of all the evidence so that a fully informed decision as between alternative course of action becomes possible. Reliability study. Statistical and Probablistic approaches to design of elements and machines.	The design of a piece of mechanical plant to a specification. 3 case histories of major design projects showing the behaviour of the designer and his team, and the consequences of his decisions. 3 assignments on these cases and associated reading and experience.

Seminars are given on various aspects of the coursework commencing with the necessary background technology and recommended schedule of work to complete the study by the due date. The case material provides illustrations of the way in which engineers in fact may operate, and how often important decisions may be taken on apparently intuitive grounds.

The format of a designer's presentation is discussed and the nature and value of a designer's note book is emphasised. Professional design practice is related where possible to the theory and techniques of design.

The study is completed by the end of the second term.

3. Some additional course topics.

The selection of materials. A systematic approach using a 'materials optimiser' system.
The analysis of machine element fractures in service.
The design development of some item of mechanical plant - e.g. heat exchangers.
The influence of manufacturing processes on the reliability of machine elements.
Lectures by visiting engineers, e.g. a local designer on an item of plant design. A consulting engineer on his philosophy.
The organisation and management of the design team.
The biography of an eminent engineer/designer/manager.

4. <u>Textbooks and References.</u>

<u>Texts:</u> Adams "Conceptual Blockbusting".
Thring & Laithwaite "How to Invent".
Von Fange "Professional Creativity".
Johnson "The Optimim Design of Mechanical Elements".
Siddall "Analytical Decision-making in Engineering Design.
Starr "Product Design and Decision Theory".

<u>Reading:</u> Glegg "The Selection of, the Science of, and the Design of Design". A Triology.
Koestler "The Act of Creation".
French "Engineering Design".
Chaddock "Art, Technology and Science in Engineering Design".

<u>Cases:</u> Can soldering system design. W.H. Smith.
The Jet Engine, extract from "The Sources of Invention" p 314, Jewkes.
The EMI Scanner. CEI. Case Study 75/03.
A Boomboat Drive and Steering System - McKechnie.
The Flixborough Disaster. Report of Inquiry.
Principles and Precedents in Engineering Design - P.J. Booker.
Notes on the life history of Henry Royce.
Jack Ryan "My Design Philosophy".